A TRANSCEIVER FOR DIRECT PHASE MEASUREMENT MAGNETIC INDUCTION TOMOGRAPHY

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Abstract- **Magnetic Induction Tomography (MIT) is a technique for imaging the electromagnetic properties of materials. Excitation coils are used to induce eddy currents within the sample volume which are then sensed by receiver coils. The technique has attracted interest for biomedical application due to the non-contacting nature of the measurements, which may provide advantages over electrode based impedance tomography in certain applications.**

The paper describes a transceiver designed for use in a prototype biomedical MIT system operating with a single excitation frequency of 10MHz. To improve channel isolation and phase stability during signal distribution, the received signals undergo heterodyne downconversion to 10kHz, filtering and limiting at the transceiver. Direct phase measurement between the downconverted reference and received signals is then undertaken to measure the signal perturbation due to the induced conduction eddy currents.

***Keywords* - Magnetic Induction Tomography, Electrical Impedance Tomography**

I. INTRODUCTION

Of the techniques for imaging the electrical properties of materials, Electrical Impedance Tomography (EIT) has attracted the most interest and undergone the furthest development. In biomedical applications however, EIT suffers from a number of operational problems associated primarily with the electrode-tissue interface such as image distortion due to errors in electrode placement.

Replacing current injection and sensing by electrodes with current induction and sensing by coils has been proposed as a means of addressing some of the problems associated with the use of electrodes in EIT, with the technique termed Magnetic Induction Tomography (MIT) [1,2].

A major problem to be overcome in developing a practical biomedical MIT system is to accurately measure the small perturbation of the received signal due to the induced eddy currents given the relatively low conductivity of biological tissues. The signal resulting from conduction eddy currents within tissue has a phase lag of 90° to the excitation field. Phase sensitive detection [1] and direct phase measurement between the received signal and the excitation signal [2] have been suggested as suitable data extraction techniques.
High frequency operation offers advantages for biomedical MIT in terms of the larger induced signal amplitudes to be expected. Phase stability and cross channel isolation during the distribution of signals around a multi-channel system becomes problematic at high frequencies. In the MIT system described by Korjenevsky and Cherepenin [3] these issues are addressed through the use of heterodyne downconversion of the received and reference signals at the receiver modules, from 20MHz to 20kHz, prior to signal processing and distribution.

The expected perturbation of the received signal due to conduction eddy currents within biological tissues, even with the use of HF excitation fields, is small. Modeling [4] and single channel measurements [1] suggest that direct phase measurement systems may require a precision of the order of 0.003° in order to resolve a 1% variation in the B field perturbation produced by a typical biological sample.

This paper describes a transceiver designed for use in a prototype biomedical MIT system. The transmitter operates at 10MHz and drives 60mA into a 4 turn induction coil. The receiver incorporates a high frequency instrumentation amplifier, downconverter, amplifier, bandpass filter and comparator. The output of the receiver is a 10kHz pulse which is then distributed for direct phase measurement. Both the transmitter and receiver may be placed in a high impedance disabled state allowing isolation of the coils when not in use. The results of measurements characterising the single channel system are given.

II. METHODS

A. *Transmitter*

The signal source for the transmitter (Figure 1) is a 10MHz crystal oscillator module (AEL1211CSN) which is enabled when the channel is to be used as the transmitter channel. The OPA3682 is a triple video op amp and is set up as a balanced driver for the transmitter coil. The OPA3682 was chosen for its high bandwidth of 240MHz and its high output current, specified as 150mA maximum. In practice it was found that significant signal distortion took place with a current drive above 60mA. A transmitter coil of 4 turns (2.5cm radius) was found to provide a suitable dynamic impedance for this current limit. The OPA3682 features a disable function which places the inputs into a high impedance state of 100kΩ in parallel with 2pF, and therefore allows isolation of the transmitter coil when not in use. The AD8056 amplifier is used as an impedance matching buffer between the oscillator, and the OPA3682.

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Abstract

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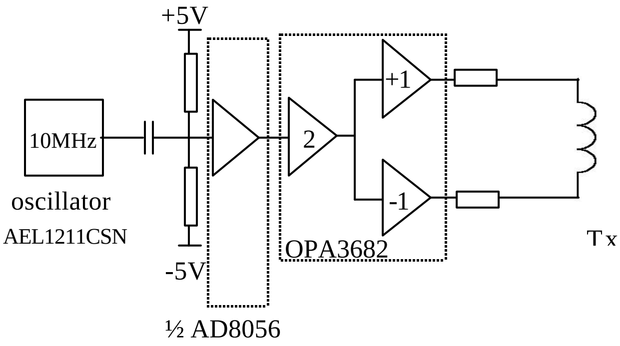

Fig. 1. Transmitter Circuit

B. *Receiver*

The receiver coil is a 5 turn 2.5cm radius coil. An OPA3682 is used as the receiver front end, and is configured as an instrumentation amplifier with a gain of two allowing conversion of the received signal from balanced to unbalanced while providing some rejection of capacitive pickup which is expected to be common mode. A centre tap to ground through a 150Ω resisitor is placed on the receiver coil allowing a DC bias current for the OPA3682 while allowing a high, and symmetrical, input impedance.

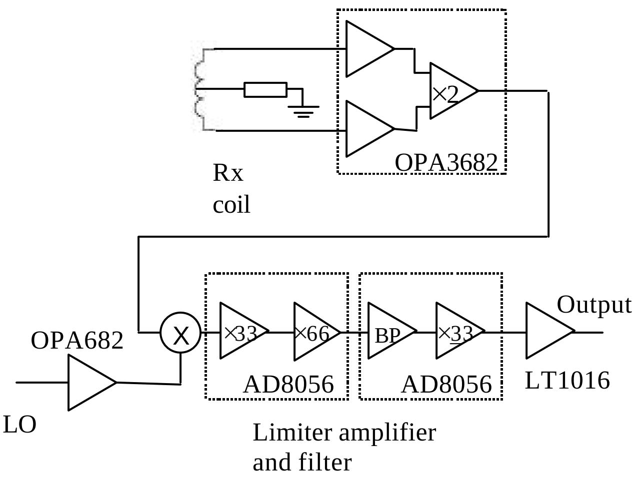

Fig. 2. Receiver Circuit

The output of the OPA3682 is then mixed with a 9.99MHz local oscillator signal. The resulting signal undergoes three stages of amplification (97dB in total) and filtering (1st order bandpass filter with –3dB attenuation at 8kHz and 12kHz) with a limiting action produced simply by operating the amplifiers in saturation. The limited signal is finally passed to a zero-crossing detector utilising a LT1016 comparator.

C. Measurement Setup

Two transceivers, composed of the transmitter and receiver circuits previously described, were placed in metal boxes (6cm width, 11cm length, 3cm depth) and attached to a cylindrical metal screen (35cm diameter, 25cm height). A 9.99MHz signal was split and distributed to both modules via coaxial cable. One of the transceiver modules was set to transmit (transmitter and receiver active) and the other to receive (transmitter disabled, receiver active). The receiver module was attached to a 5 turn receiver coil, while the receiver of the transmitter module was attached to a single turn 2.5cm radius coil, providing a reference signal.

The outputs of the modules were distributed to an XOR gate (74HC86) as shown in figure 3.

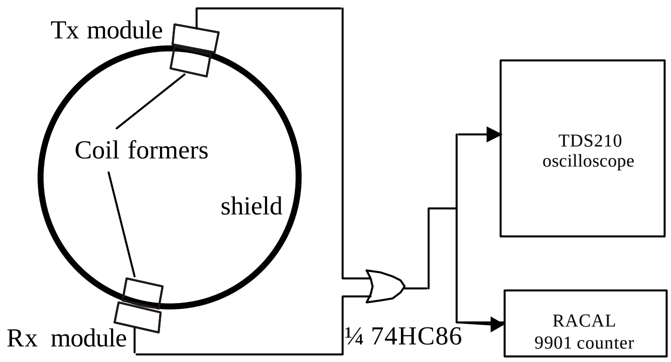

Fig. 3.Measurement Setup

The standard deviation of the output pulse widths, which should be directly proportional to the phase offset between the received and reference signals, was measured by collecting individual pulse widths with the automatic measurement facility of a Tektronix TDS210 oscilloscope. Drift was estimated by collecting 100000 pulse averages over a 15 minute period on the Racal 9901 counter.

In order to compare the phase precision performance of the transceivers with a representative measurement of perturbations produced by a sample of conductivity within the biological range, a 3S/m beaker of saline (9.5cm diameter, 15cm height) was placed equidistant, and centrally, between the transmitter and receiver coils. The beaker was then displaced laterally on a line drawn equidistant from both coils, and the pulse width was measured for each position by collecting 1000 pulses on the Racal 9901 counter.

III. Results

The standard deviation of individual pulses, over a series of forty measurements with an empty detector volume, was found to be 165ns corresponding to 0.6°.

After switching on the channels it was observed that a significant amount of phase drift occurred during the first 5 minutes of operation, with a change of average phase of approximately 0.15° during this period. A plateau region was achieved after 5 minutes of operation, and it was found that the maximum drift during a 15 minute measurement period was 14ns or 0.05°.

The results of the measurement utilising the beaker of saline, collected by taking 10 samples of 1000 pulse averages per position are shown in figure 4 (shown by full line).

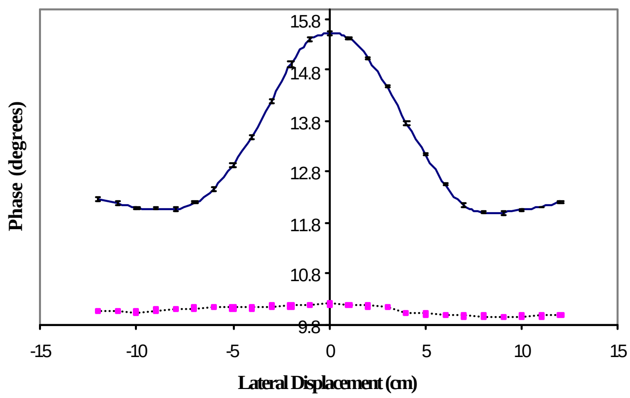

Fig. 4 Measured Phase vs Lateral Displacement

The range of the measured phase offset was 3.5° over the lateral displacement range of –12cm to +12cm. The average standard deviation of the measurements was 0.029° (1000 sample averages).

The measurements were repeated using an identical beaker filled with deionised water, and the results are shown by the dashed line. The range of the measured phase in this case was 0.25° with a maximum at the central (displacement = 0cm) position. The average standard deviation was found to be 0.02° over this set of measurements.

IV. Discussion

A practical benchmark for biomedical MIT is to be able to resolve 1% variations in the B field perturbations expected from biological tissues. For tissues with conductivities in the biological range of 0.1S/m – 2S/m, the maximum phase shifts expected, operating at 10MHz, are of the order of 1°. Practical *in vivo* imaging is therefore likely to require MIT systems with better than 0.01° phase precision, and with reasonable data acquisition times.

The system described provides a 100 sample average resolution of 0.06°, with a corresponding data acquisition time of 0.01s. The major limiting factor for phase resolution appears to be the received signal amplitude. In measurements aimed at characterising the phase precision of the receiver modules [5], it was found that the receivers provided better than 0.2° individual pulse standard deviation down to an input amplitude of 8mVpp, with the pulse standard deviation rapidly deteriorating below this limit.

The initial drift on startup should not be significant since the major contribution to heating are the coil driver amplifiers. These will not be used continuously, but in short bursts corresponding to the single channel acquisition time, liable to be well under 1s.

Of greater concern are the results obtained with deionised water. The change in measured phase offset found (0.25°) suggests that the residual direct coil to coil electric field linkage is at present far too large and needs to be addressed by the use of shielding on either or both sets of coils.

Acknowledgment

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